

Multi-Directional Fall Risk Assessment

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INTRODUCTION: About one-third of older adults over 65 fall at least once a year, inducing 55.8% of accidental deaths in older people (Osoba et al., 2019). Non-fatal falls caused 44 billion US dollars spent on lifetime healthcare costs in the United States in 2014 (Haddad et al., 2019). Therefore, advancing the predictive, preventative, and rehabilitative methods aimed at reducing the risk of injurious falls is imperative. However, current available perturbation systems lack the ability to simulate real-world slips in random oblique directions. In this study, we developed servomotor-controlled platforms that can precisely simulate balance perturbations in any direction and used them to evaluate human balance control ability during single-leg standing.

METHODS: Two servomotor-controlled multi-directional sliding platforms were created. Researchers can control the platform to generate balance perturbations in Anterior/Posterior (A/P), Medial/Lateral (M/L), and any oblique directions (combinations of both A/P and M/L directions). The study was approved by the Institutional Review Board of the University of Maryland, Baltimore. After providing written informed consent, seven young adult participants (three males and four females) were recruited in a pilot test, during which 1) one platform simulated balance perturbations in eight directions with a slow speed mode (maximum velocity is 20cm/s), including A/P, M/L, and four oblique directions at 45-degree intervals, while the subjects stood on the platform using the left/right leg (Figure 1a); 2) both platforms generated balance perturbations in the same directions simultaneously with a fast speed mode (maximum velocity is 35cm/s) when the participants stood on both platforms and evenly distributed their body weight (Figure 1b). The participants were unaware of the timing and directions of the perturbations. Their body motions during the perturbation were captured by six inertial measurement units (IMUs, Shimmer3) that were placed on the sternum (below the suprasternal notch), L5, and the middle-lateral side of both thighs and shanks. The footplate reaction forces were measured by two JR3 sensors and the center of pressure would be calculated. A harness system was utilized to protect the subjects from falling and the force exerted on the harness was measured by a uniaxial force sensor. The steady or balance loss trials were identified with a careful visual inspection of the video records.

RESULTS SECTION: Our sliding platforms successfully generated balance perturbations in all eight directions with a displacement of 6 cm. For the perturbations at the 45-degree intervals, the sliding platforms generated sliding in A/P and M/L directions with the same velocity at the same time, yielding perturbations at 45-degree intervals precisely. For the single-leg standing, all volunteers exhibited balance loss during the perturbations in the anterior-medial direction, while for the double-leg standing, three out of seven subjects lost balance during the perturbations in the anterior direction which was therefore identified as the riskiest direction for double-leg standing. Two representative single-leg standing trials of the same subject were shown in Figure 2 (steady) and Figure 3 (balance loss) which indicated that subjects showed different responses to perturbations in different directions which can be detected by the IMUs.

DISCUSSION: The perturbations created by our servomotor-controlled sliding platforms proved to result in instability during both single-leg and double-leg standing. Therefore, the results endorsed that our sliding platforms can be used in fall risk evaluation and fall prevention training. A sequence of the signal fluctuation of sensors on the shanks, thighs, L5, and sternum was identified which could facilitate the understanding of the fall mechanism and human balance control ability during perturbations in different directions. The lifting force exerted on the harness system could distinguish balance loss from fall using the criteria of Yang and Pai (2011). However, as Yang and Pai's criteria are for walking slip training, an accurate classification of the outcome during standing perturbation training is necessitated which can promote the proper assessment of the effectiveness of our sliding platform-based fall prevention training, and the body acceleration signals may be used as predictors to classify the outcome as indicated by Figure 2&3 (the subject exhibited different responses during steady or balance loss trials). However, due to the limited data size, no statistically meaningful analysis toward identifying the most vulnerable direction and the optimal predictors can be performed. We will conduct further analysis of human balance control ability against perturbations in various directions in future studies and recruit more participants including older people with and without a fall history.

SIGNIFICANCE/CLINICAL RELEVANCE: This study creates a multidimensional perturbation system that can unlock multidirectional fall risk evaluation and subject-specific training. The ground perturbation training procedure has the potential to enable home-based fall prevention exercises.

REFERENCES:

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Figure 1. Standing test. (a), single-leg standing, during which subjects have to allocate more than 85% of the body weight to one side; (b), double-leg standing, during which the body weight is evenly distributed to each platform (the difference between left and right is less than 10% of body weight).

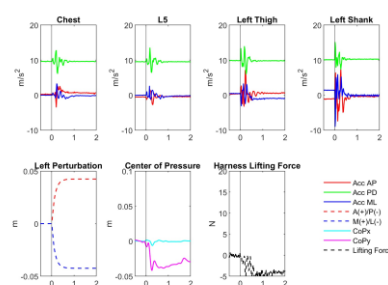


Figure 2. Subject's motion measurement during one steady trial. Acc AP, PD, ML: acceleration in anterior/posterior, proximal/distal, and medial/lateral direction, respectively; A(+)/P(-): anterior/posterior; M(+)/L(-): medial/lateral; COPx, COPy: center of pressure in x and y direction, respectively.

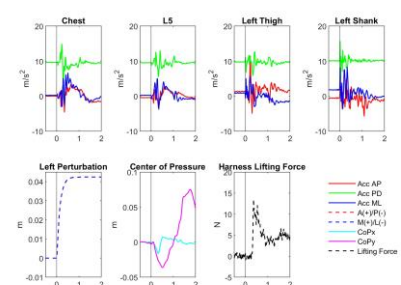


Figure 3. Subject's motion measurement during one balance loss trial. Acc AP, PD, ML: acceleration in anterior/posterior, proximal/distal, and medial/lateral direction, respectively; A(+)/P(-): anterior/posterior; M(+)/L(-): medial/lateral; COPx, COPy: center of pressure in x and y direction, respectively.